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IDENTIFICATION OF EARTHQUAKES AND UNDERGROUND EXPLOSIONS

Eugene Herrin

Southern Methodist University

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Advanced Research Projects Agency

February 1973

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SEMI ANNUAL REPORT

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

for

GRANT 71-2133 B

IDENTIFICATION OF EARTHQUAKES AND UNDERGROUND EXPLOSIONS

SMU ~~No.~~ 80-46 Do not use Ogl

Department of Geological Sciences
Southern Methodist University

February, 1973

Eugene Herrin, Professor
Principal Investigator

A.C. 214/692-2760

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13. ABSTRACT

This is a report of the progress of our research on this grant for the first six months of FY1972-1973. The research has been concentrated in several areas. Firstly, investigations of Rayleigh Wave dispersion over a continental path have shown a dispersion wave stability that has enabled the development of "chirp" (or matched) filter techniques. When suitably constructed these filters permit the detection of surface waves with low signal-to-noise ratios, and enable the separation of mixed events. Secondly, array processing techniques in frequency-wave-number space have been significantly improved. Thirdly, a method has been described for correcting the bias in the estimation of body wave magnitudes (m_b). And, fourthly, two-dimensional model studies have been used to corroborate theoretical predictions of surface wave spectra for an oceanic upper mantle model.

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Security Classification

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SEMI ANNUAL REPORT

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Program Code: 2F10
Name of Contractor: Southern Methodist University
Effective Date of Grant: 1 July 1971
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CURRENT RESEARCH

Rayleigh Wave Dispersion

Our studies using long period data recorded in northeast Texas have shown that a wave guide for long period Rayleigh waves exists from China and the southern border of the USSR to Texas. We have determined group velocity dispersion curves for a number of Rayleigh waves which have traveled through this polar wave guide. Largely through the efforts of Dr. William Tucker, a new and highly effective method has been devised for estimating the group velocity dispersion curve from digitized time series.

Figure 1 shows the data points obtained from Rayleigh waves for an event about 900 km north of Norway. A truncation and smoothing technique was used to produce, from the data in figure 1, the group velocity dispersion curve shown in figure 2. Results for three other events are shown in figures 3 through 8.

These four dispersion curves are very similar, particularly at periods greater than 30 seconds. In fact, we cannot tell whether the observed differences in these curves result from statistical fluctuations in the estimates or

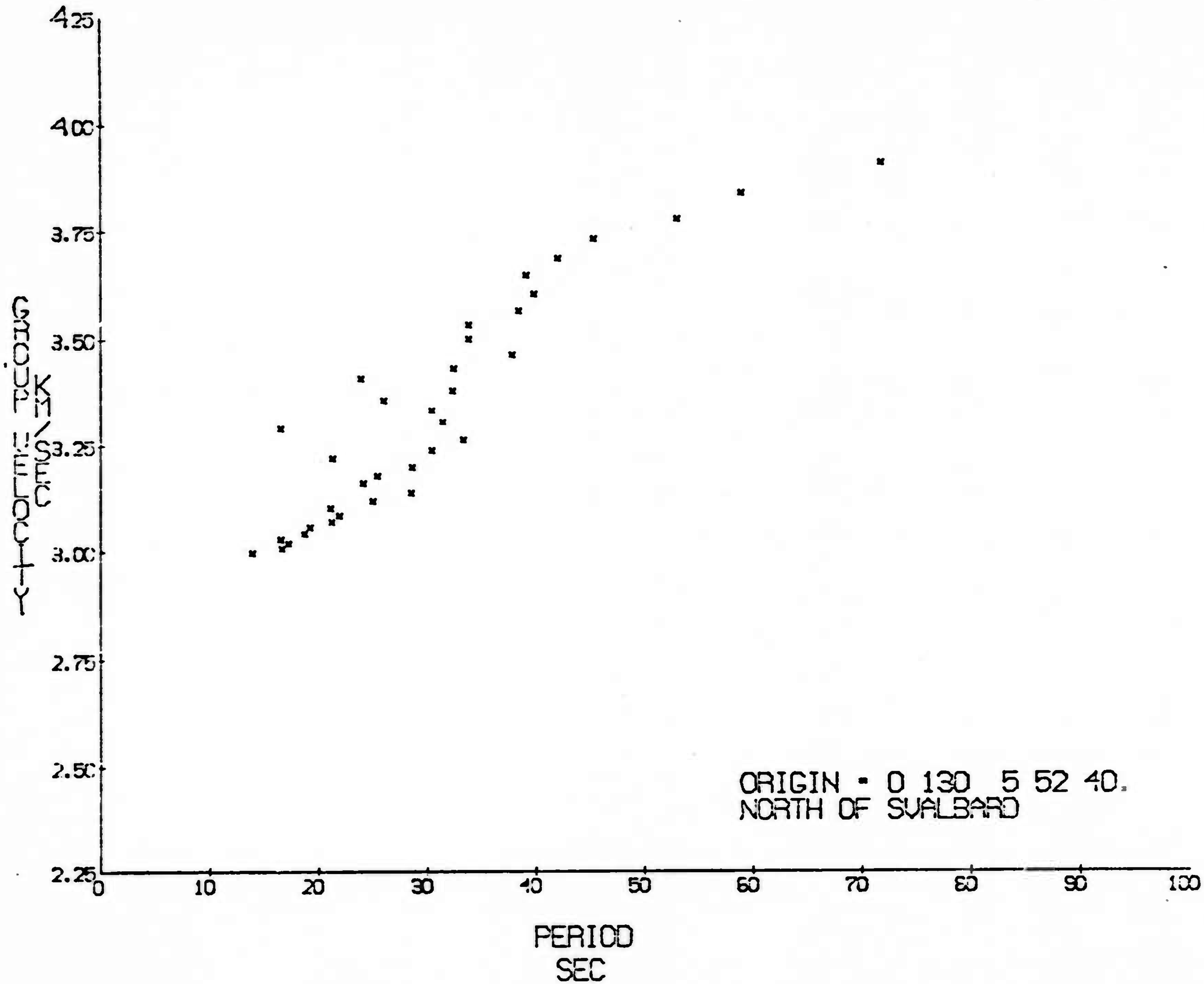
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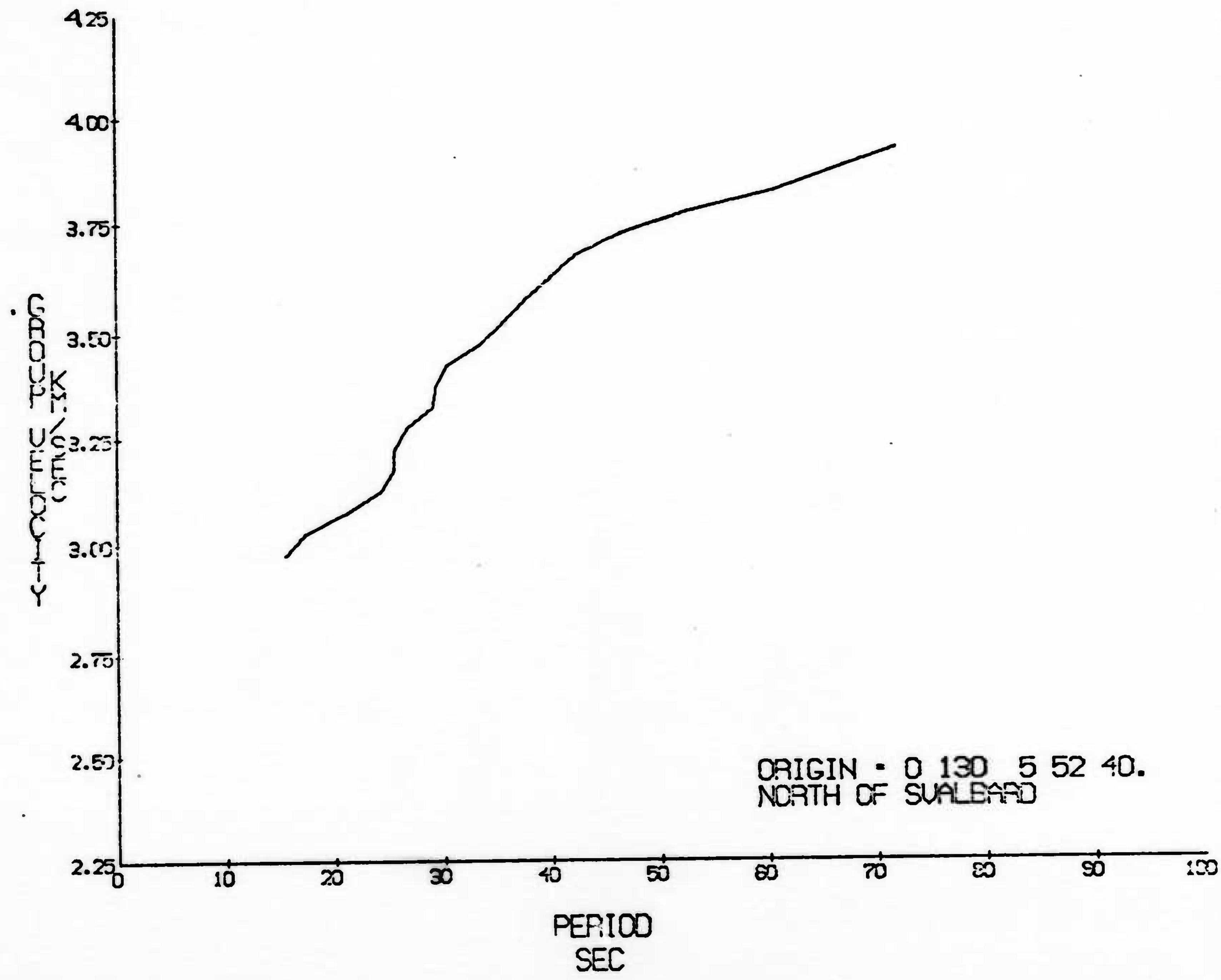
Figure 1



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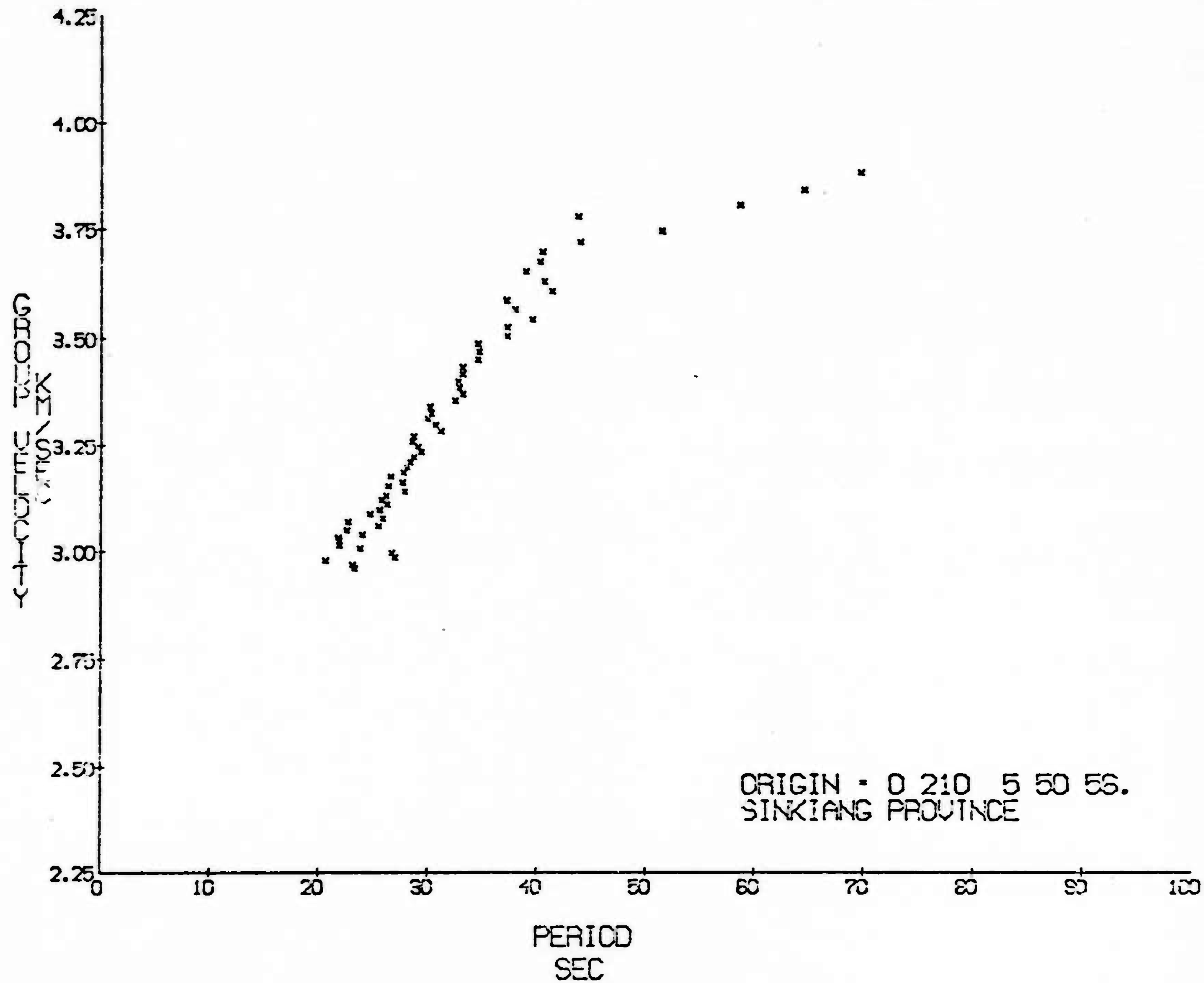
NORTH OF SVALBARD
PERIOD SEC

Figure 2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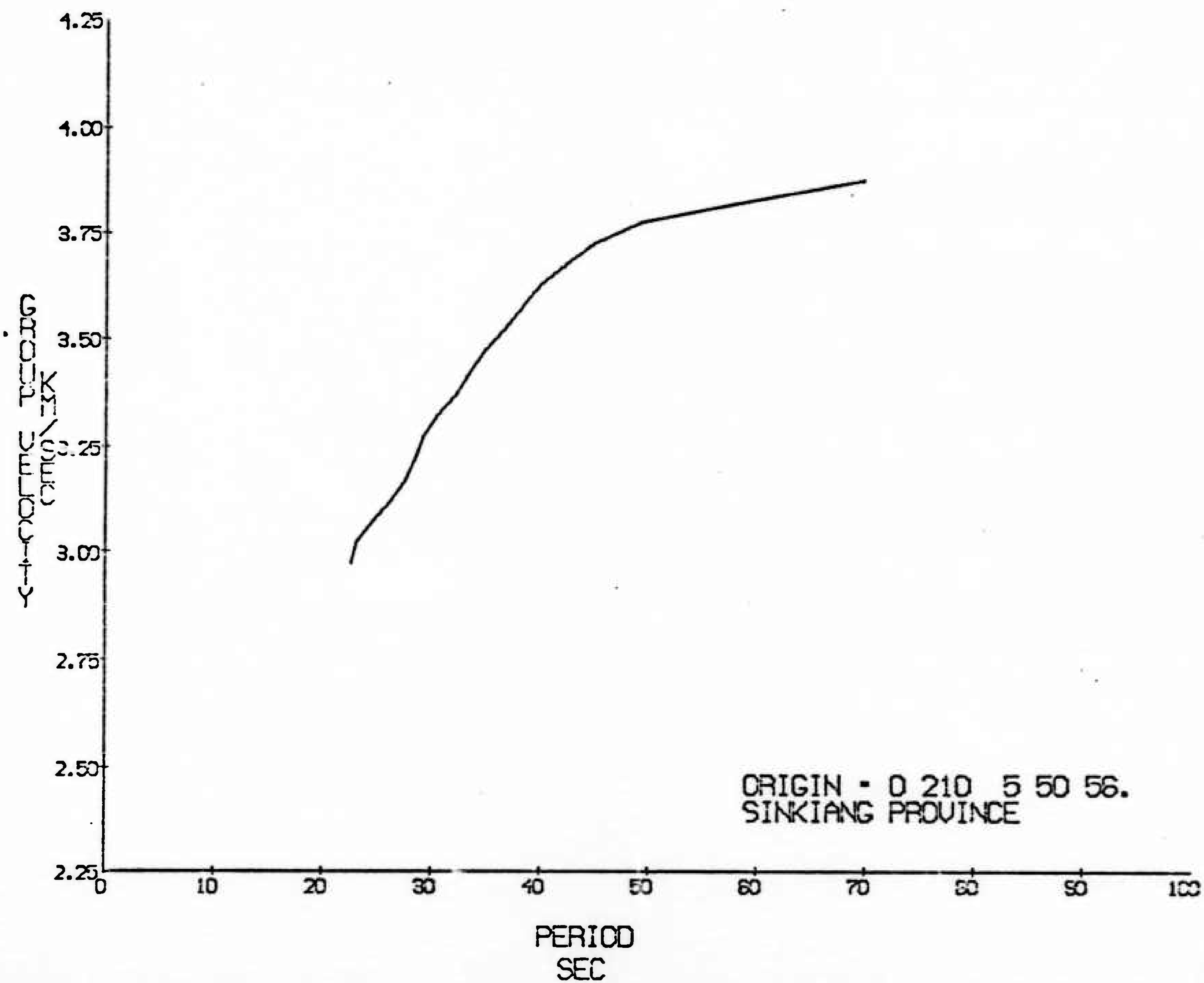
SINKIANG PROVINCE

Figure 3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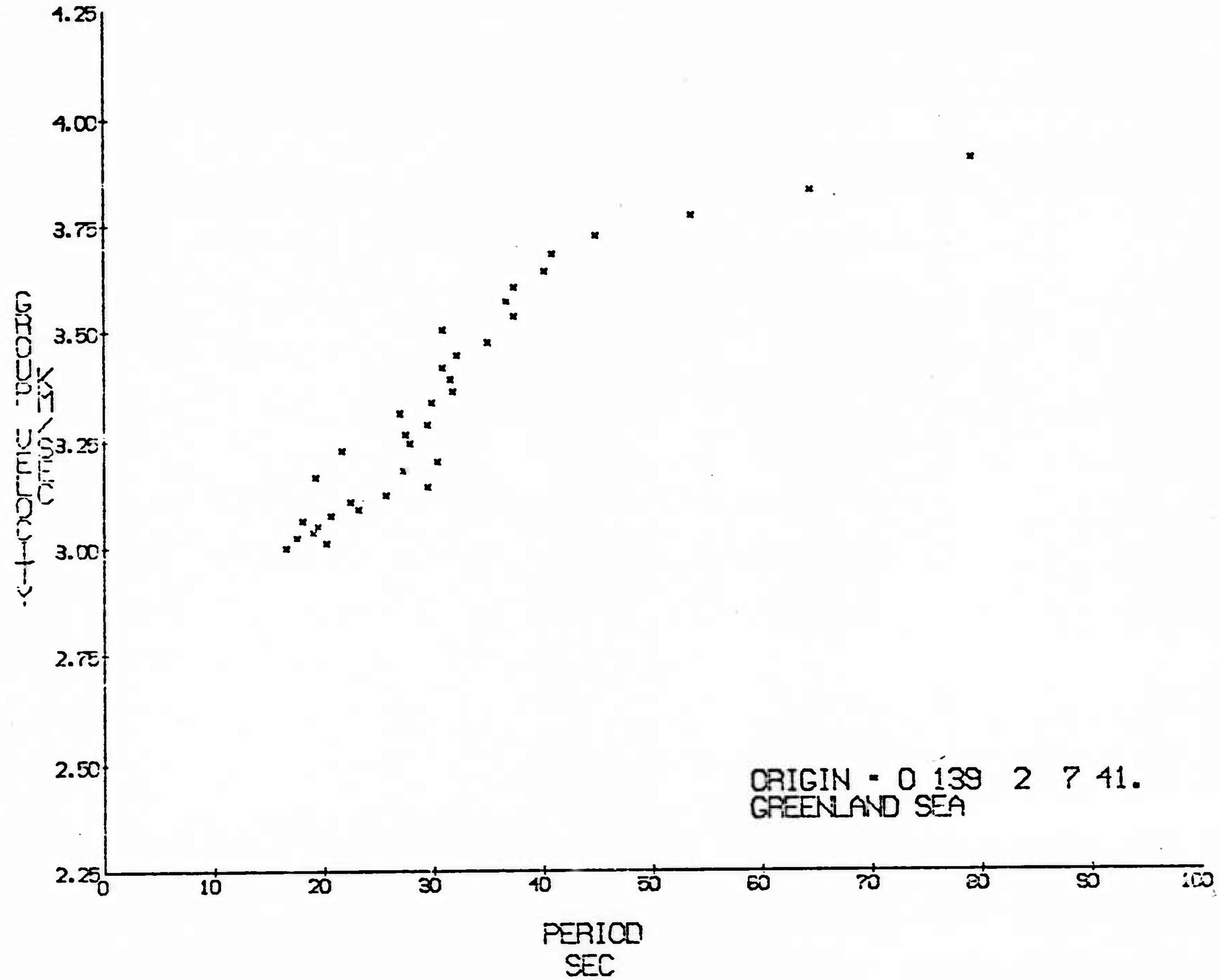
SINKIANG PROVINCE

Figure 4



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GREENLAND SEA
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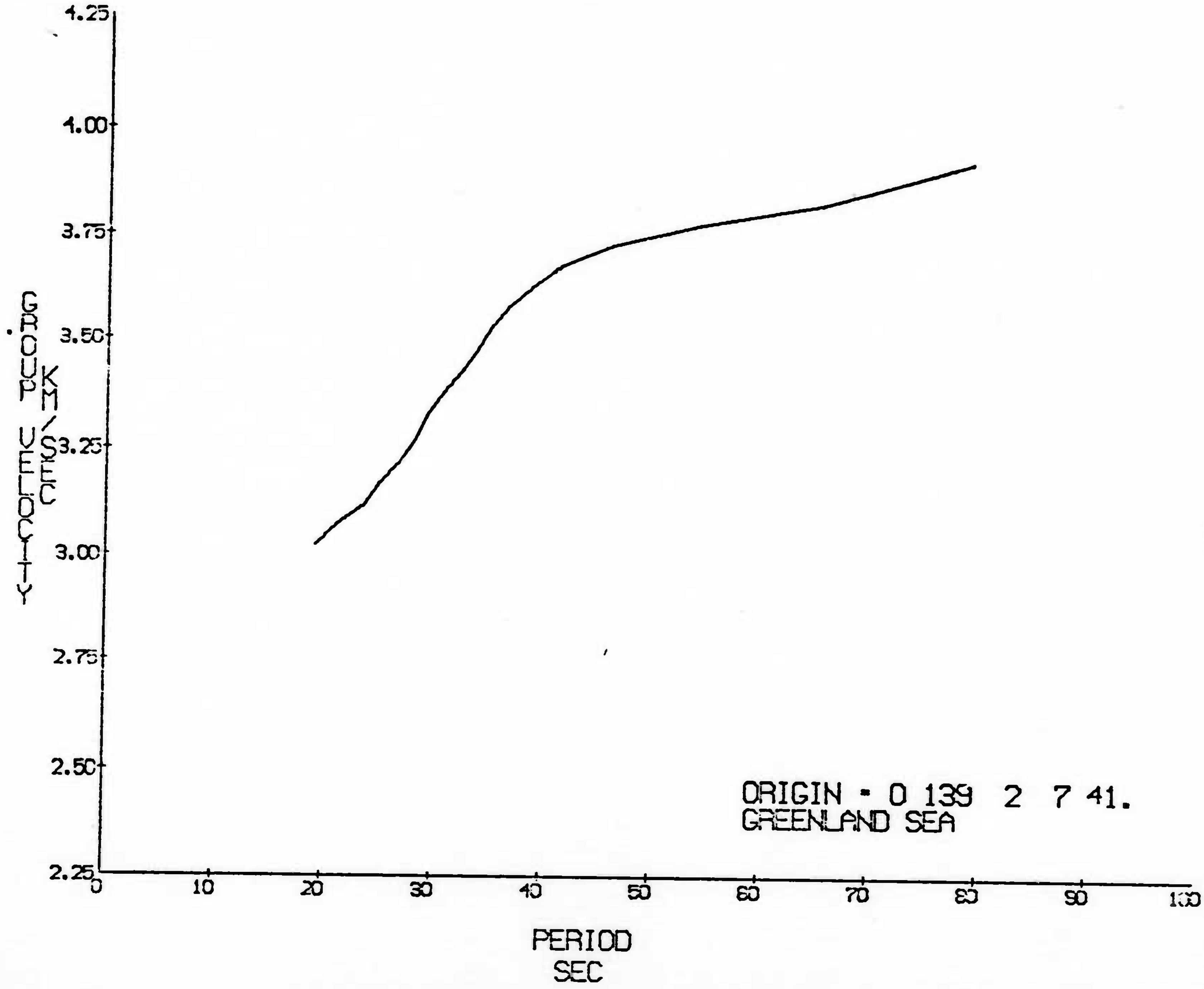
Figure 5



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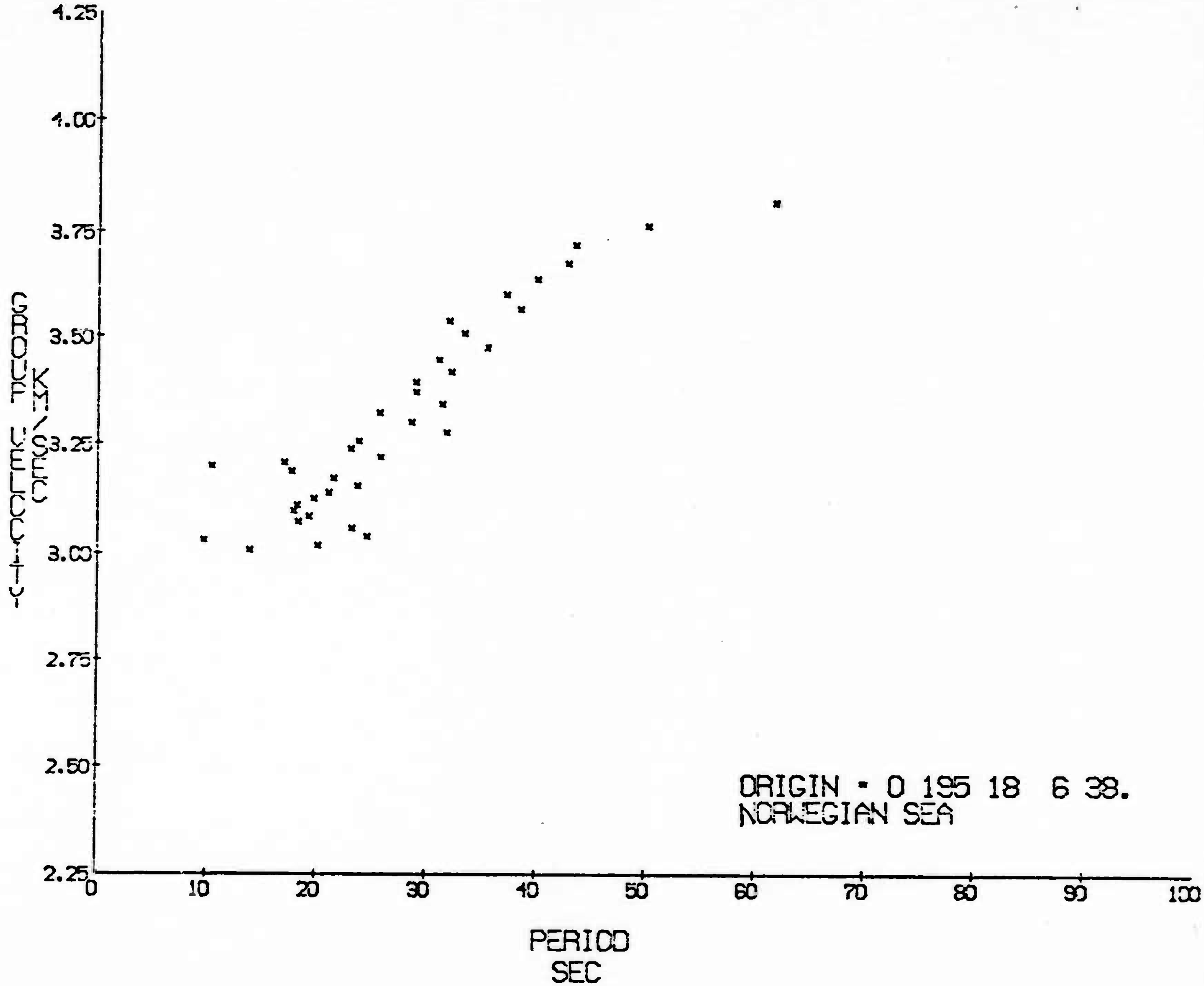
GREENLAND SEA

Figure 6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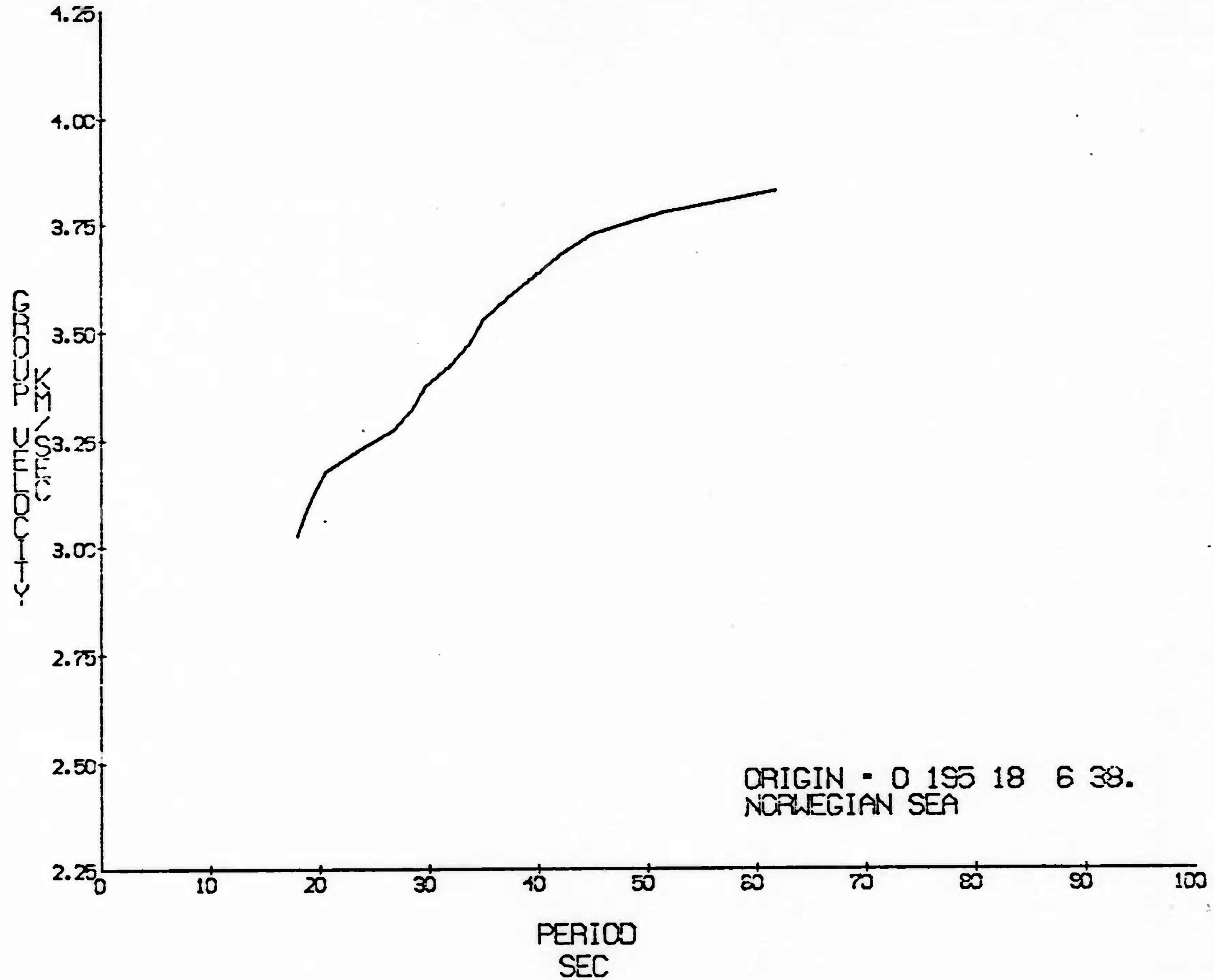
NORWEGIAN SEA

Figure 7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NORWEGIAN SEA
PERIOD
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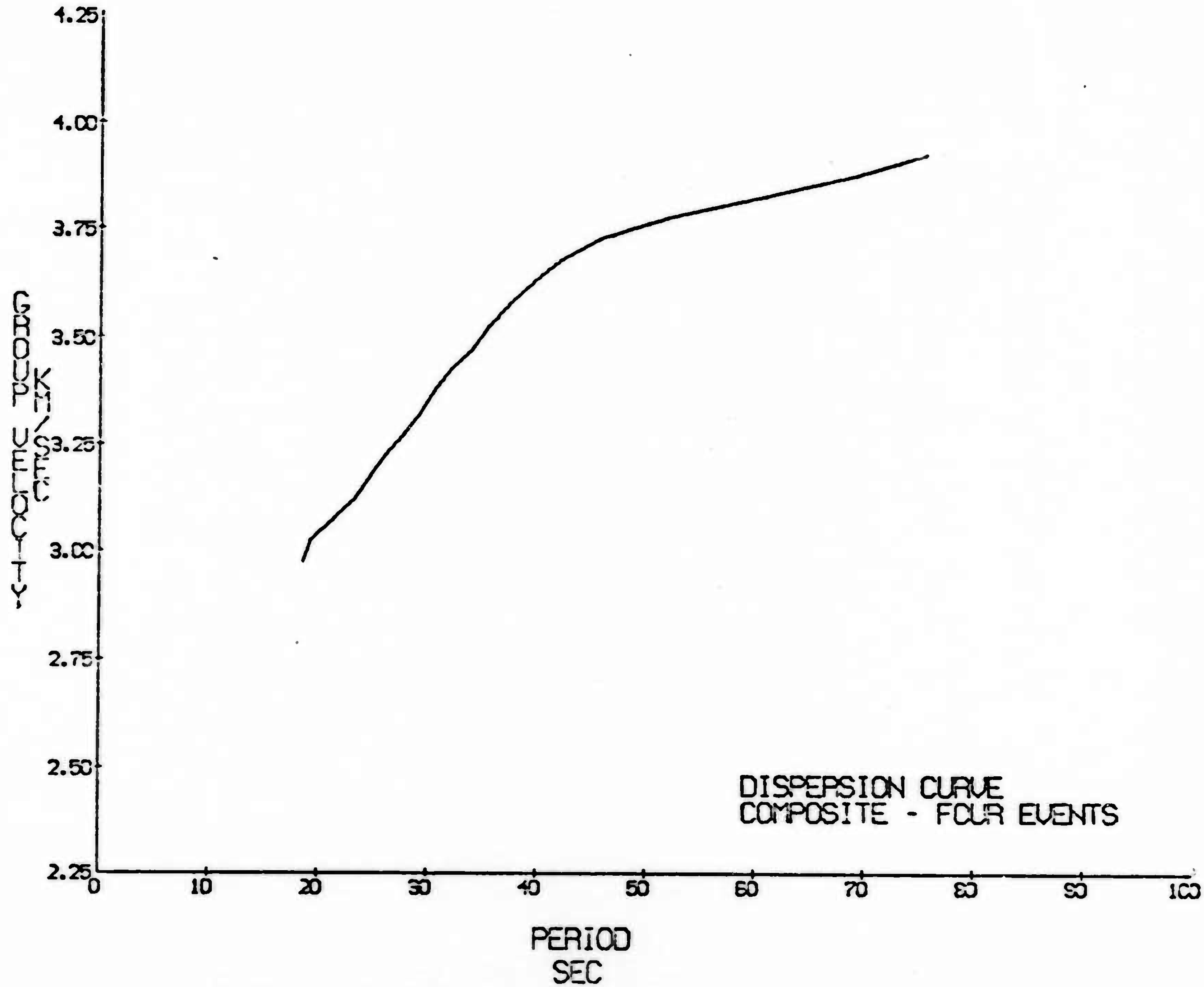
Figure 8

real differences in velocity along the propagation path.

Chirp-filter Techniques

Because of the uniformity of group velocity dispersion within the polar waveguide, particularly at longer periods, and the broad-band nature of the Rayleigh waves, "matched" or chirp-filter techniques should be particularly effective on data recorded at our northeast Texas site. We combined the data from the four events shown in the preceding section (Fig. 1-8) and computed a composite group velocity dispersion curve (Fig. 9). A program was written which will design a chirp-filter from this composite dispersion curve based on the estimated epicentral distance to the suspected event.

Figure 10 shows the application of this filter to the time series for one of the events used in calculating the composite dispersion curve. The lower trace shows the filter output, properly aligned with the input series, which ideally should look like an auto-correlation function centered at the beginning of the Rayleigh wave. Figures 11 through 13 show the time series and filter outputs for the other three events used to compute the composite dispersion curve. In all of these figures the data was plotted so that the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DISPERSION CURVE
COMPOSITE - FOUR EVENTS

Figure [illegible]

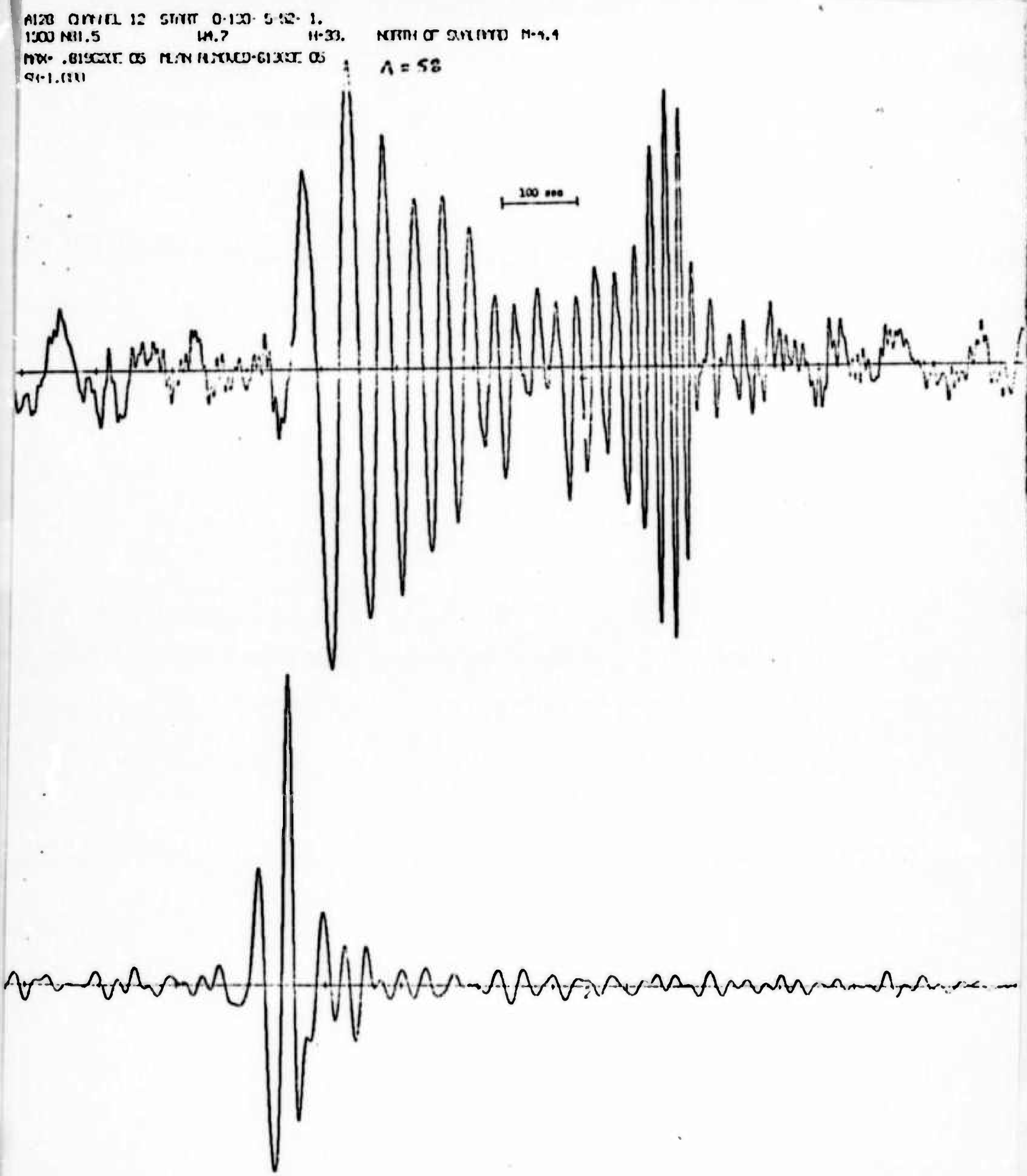


Figure 10

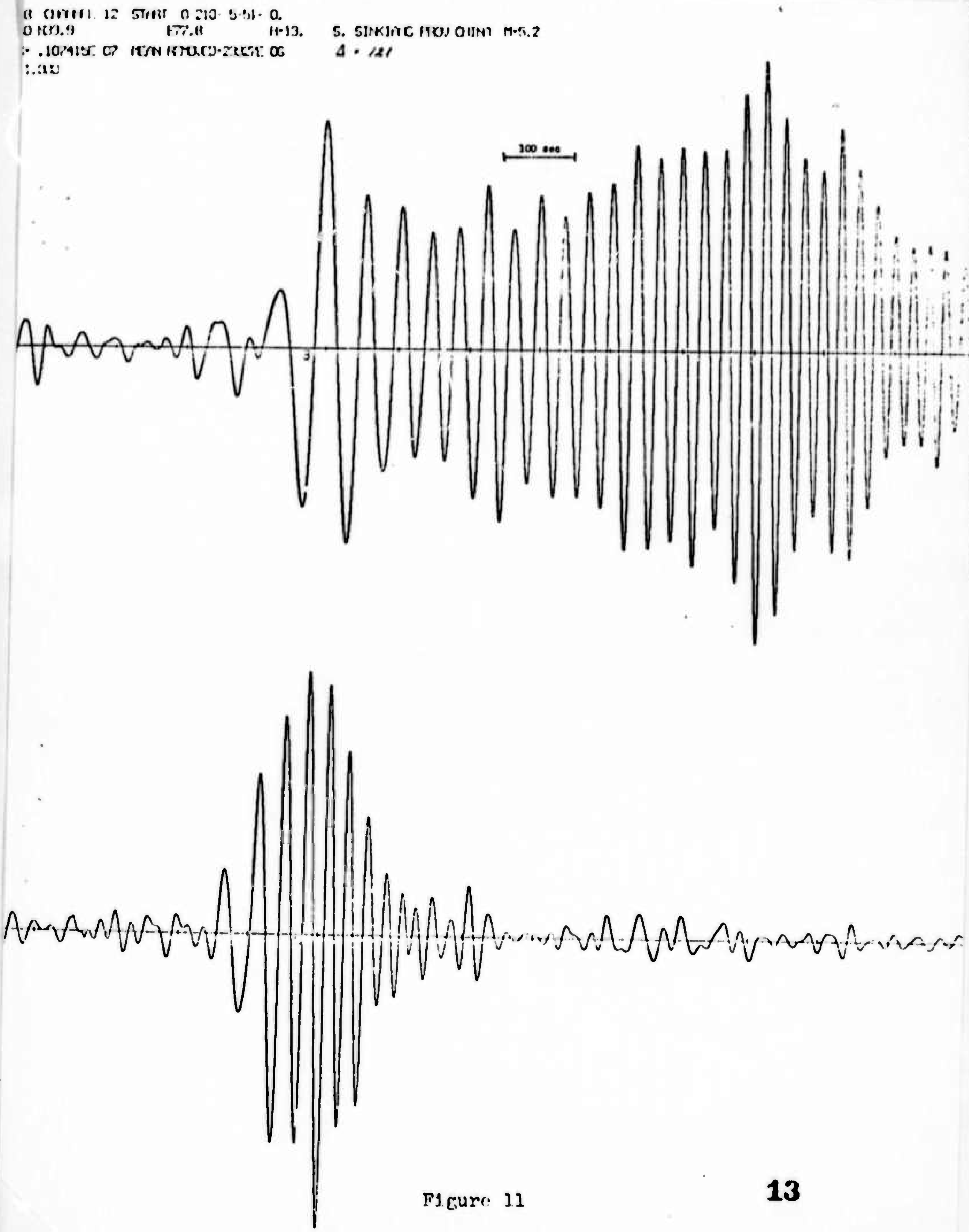


Figure 11

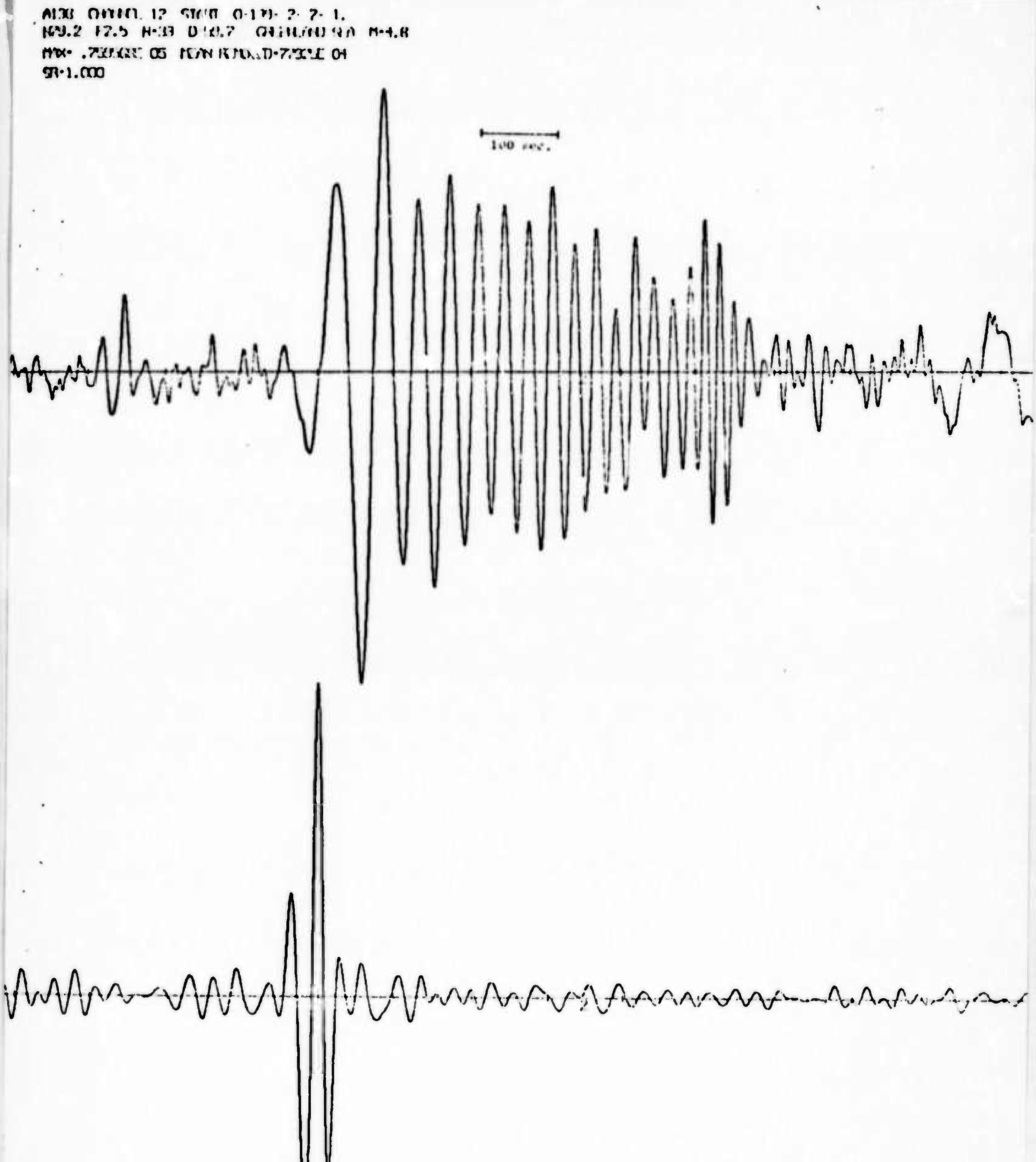


Figure 12

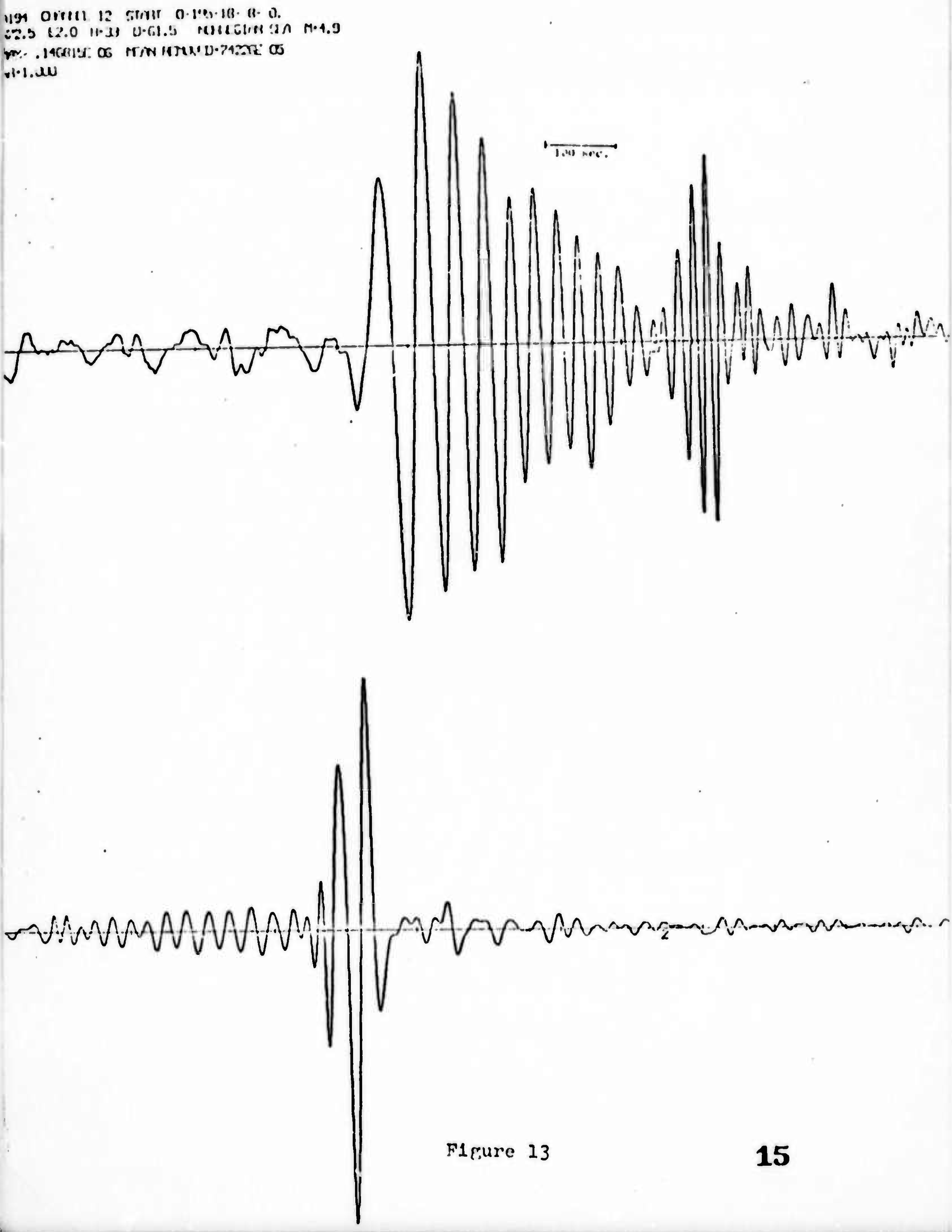


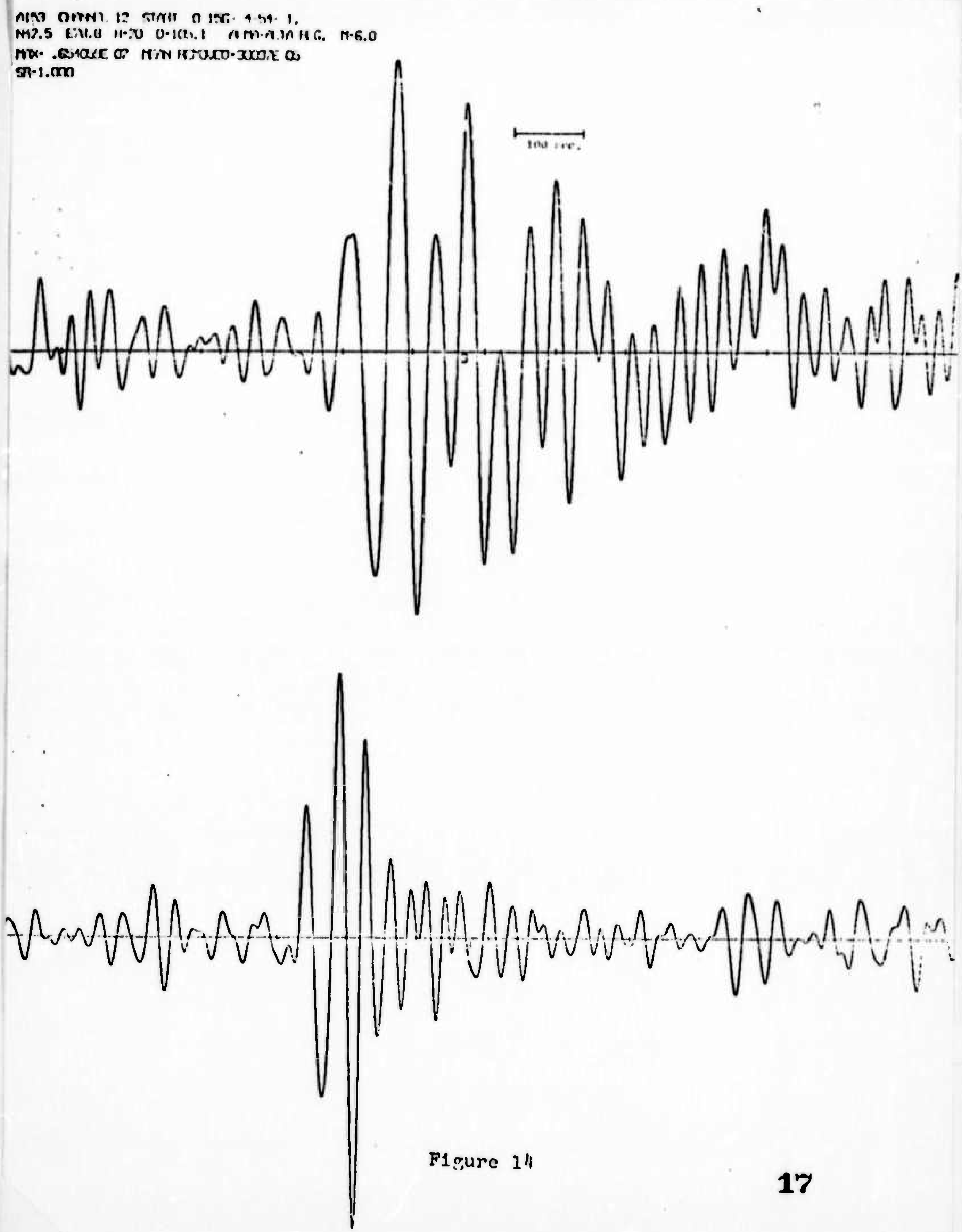
Figure 13

largest excursion was full-scale; therefore, any improvement in signal-to-noise ratio must be estimated by examining the reduction in noise. Thus the maximum amplitude of the signal or the filtered output is fixed.

Figures 14, 15 and 16 show similar results for sources in the USSR which are nowhere near the events used to construct the filter. These figures show that the same filter is effective for widely separated sources in the USSR. Figure 17 shows the filtered output from a small event, about 110 km deep, in the Hindu-Kush. Although the Rayleigh wave is hardly discernible on the vertical records, the arrival is clearly seen on the filtered output. These studies show that chirp-filter techniques can be expected to give signal-to-noise improvement of as much as X3 for Rayleigh waves propagating through the polar wave guide.

Separating Mixed Events

Mixed Rayleigh waves resulting from multiple sources close together, reflections or multipathing are very difficult to separate, even when data from large arrays are available. If these arrivals are separated by times greater than 50 to 100 sec, the Chirp-filter technique may be useful in separating the arrivals. Figure 18 (lower



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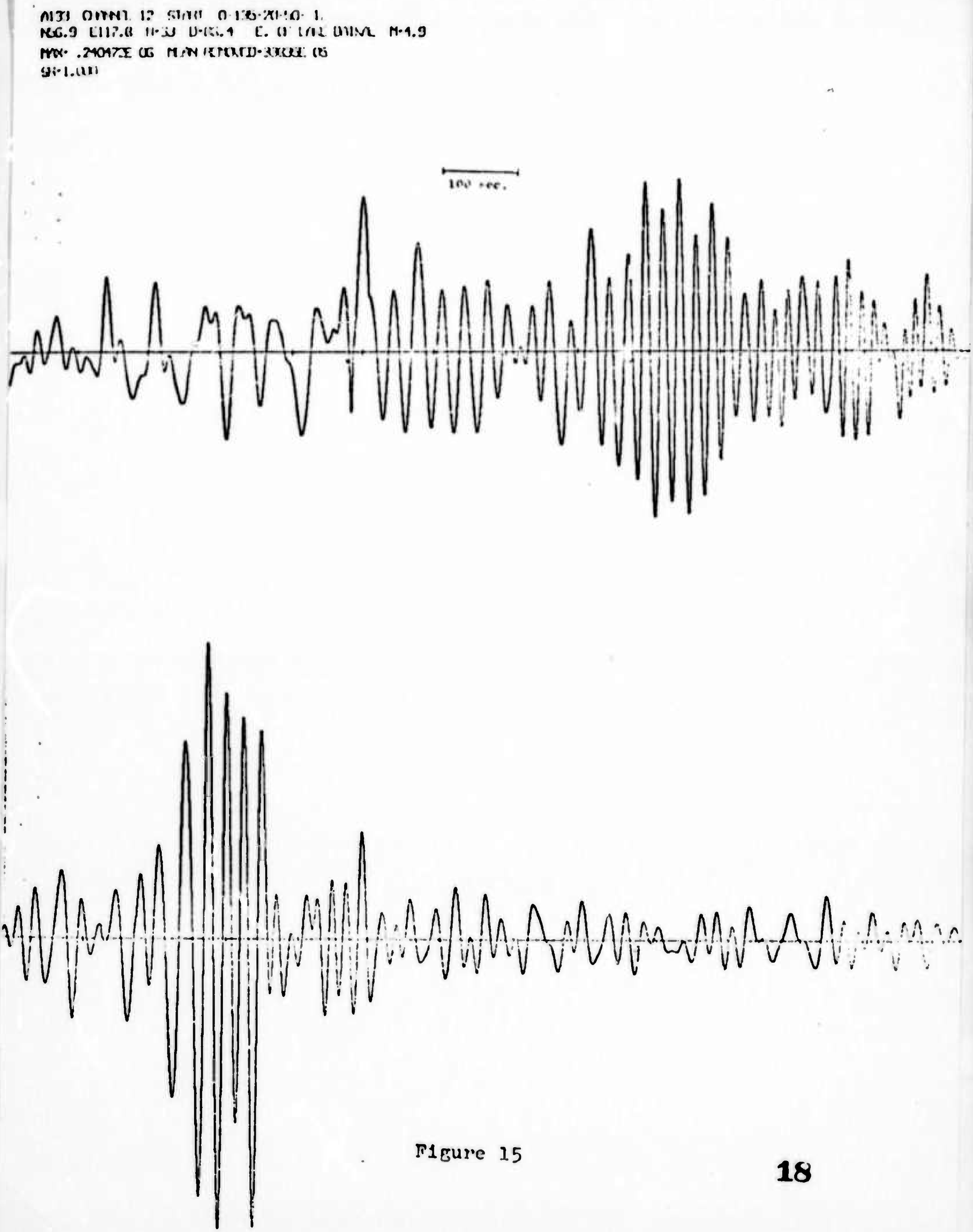


Figure 15

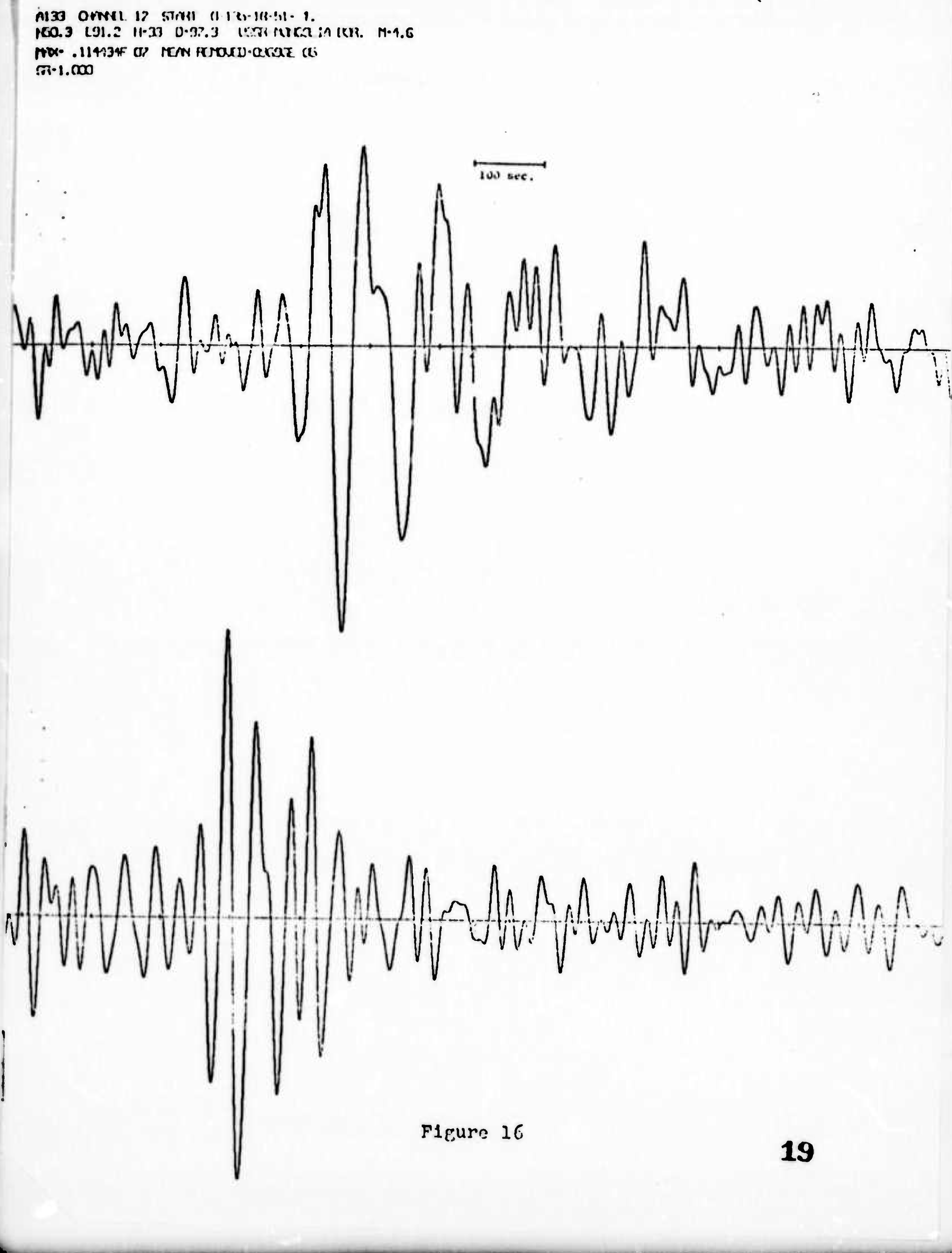


Figure 16

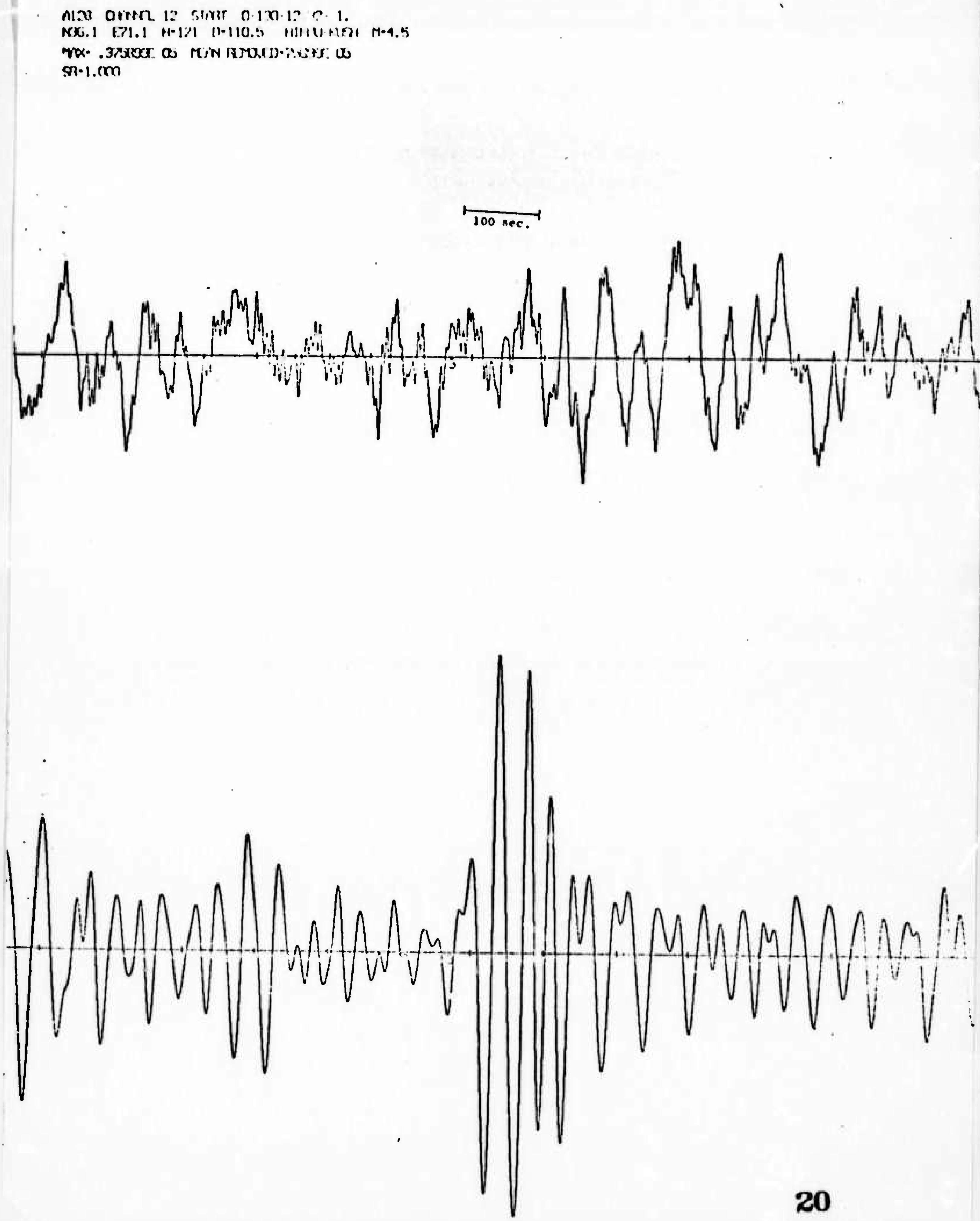


Figure 17

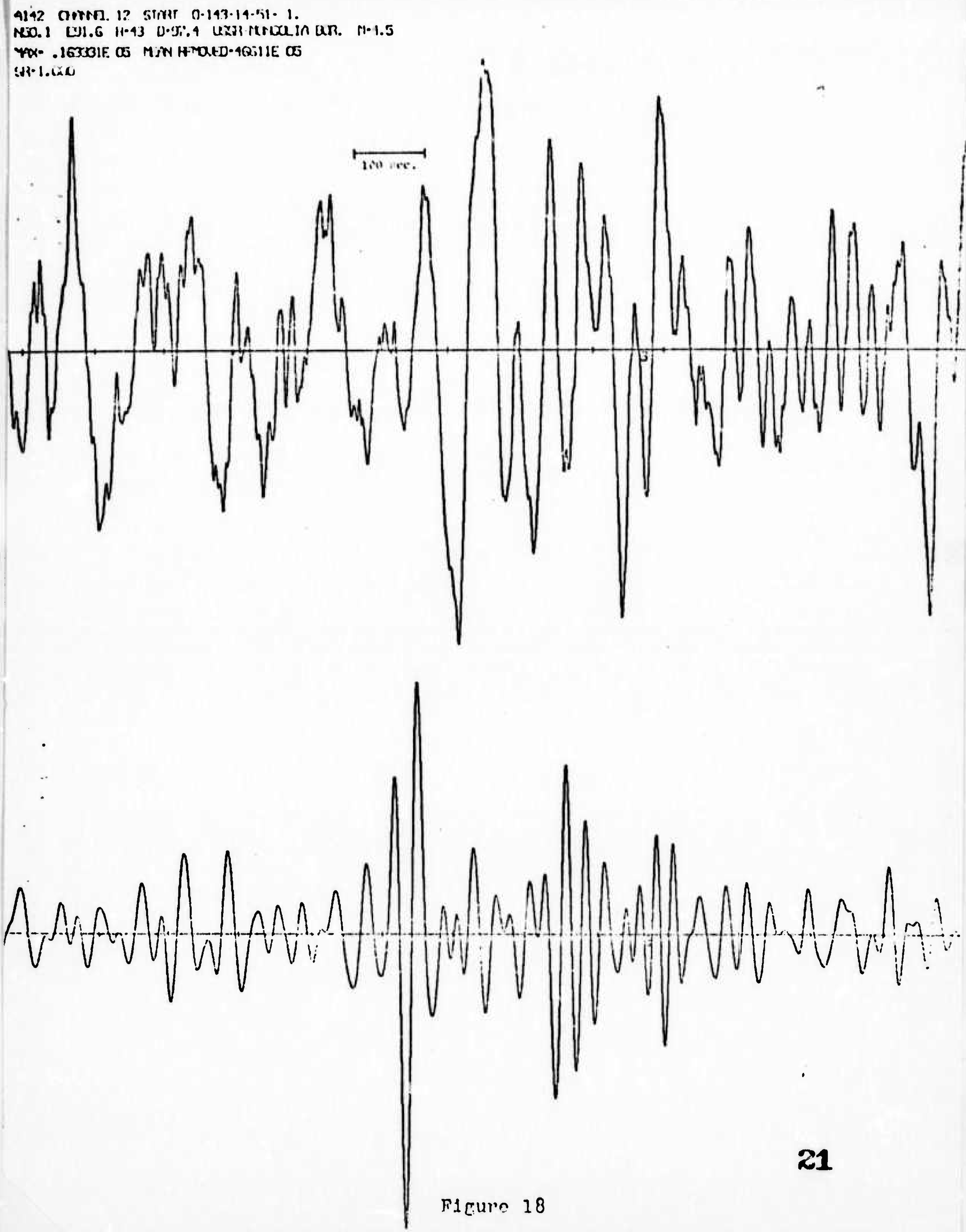


Figure 18

trace) shows the filtered output for a small event from the USSR-Mongolia border region. Due to, either a multiple source, or reflections, or multipathing, there are two and possible three Rayleigh wave arrivals shown on the filtered trace. The first and largest of these signals occurs precisely at the expected arrival time of the fundamental Rayleigh wave (as reported by NOAA) from this event. Figure 19 shows the results for another event from the same region; again there are two arrivals. We do not understand the reason for these multiples; this region is the only one where we have observed this phenomenon. The results, however, show that the chipr-filter technique applied to broad-band, long period data can be effective in separating mixed Rayleigh waves from proximate sources.

Array Processing Techniques

We have generated the principal components of a major software system for continuous general analysis of array data. The syste, called FKSCAN, transforms successive blocks of array data to the frequency-wave number domain and explores that space for correlations. The powerful advantage of transforming array data from time and physical space into the frequency-wavenumber domain is that, quite

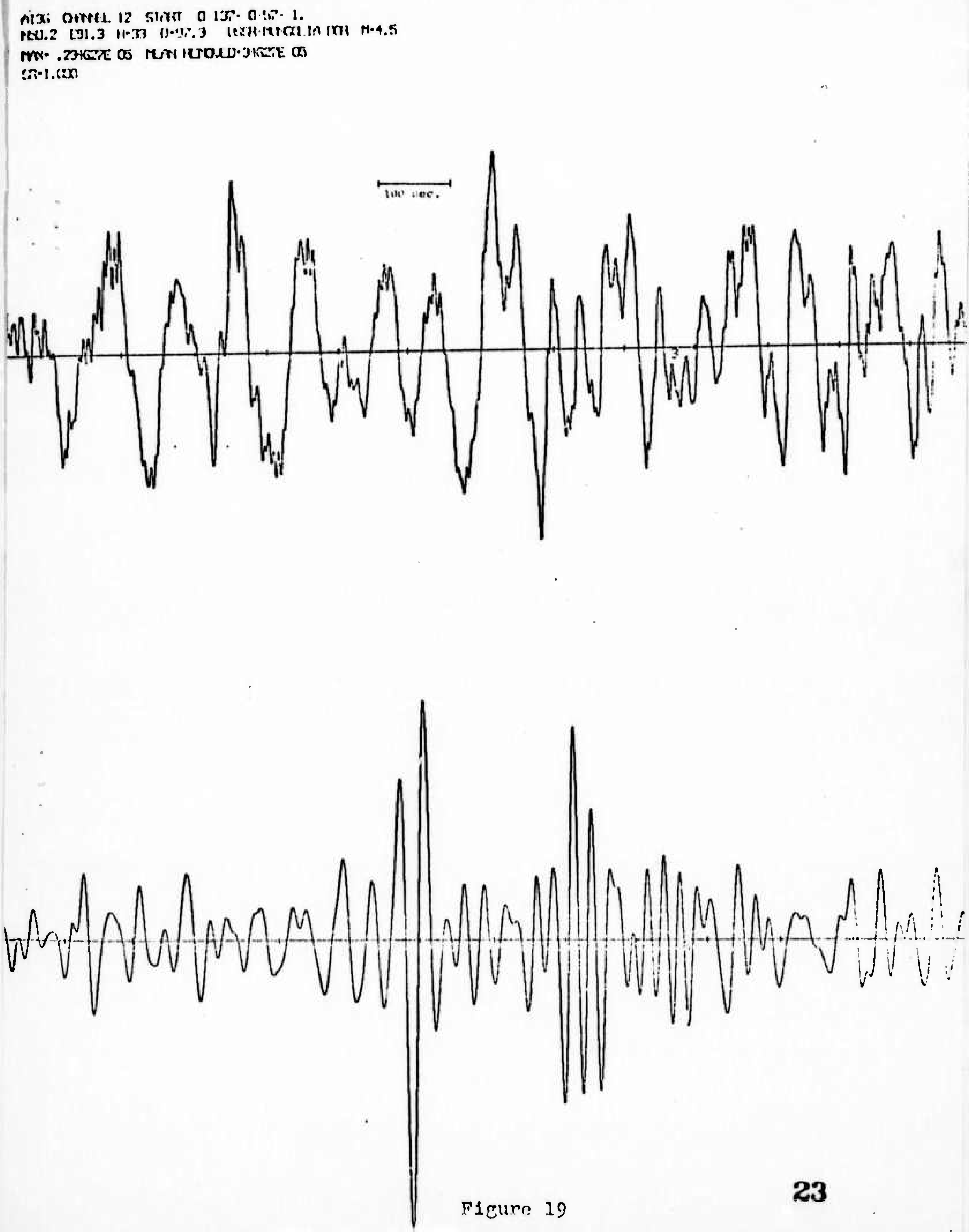


Figure 19

generally, correlations are automatically separated and sorted according to frequency, velocity, and azimuth permitting detection and description of signals not readily discerned in time and physical space. Further, spatial filtering is markedly facilitated in transform space and, as one consequence, large overriding signals may, in effect, be "turned off" after the fact to permit the detection of much smaller simultaneious arrivals. FKSCAN, after transforming and exploring each array data block, filters and removes the principal energy peak thus detected and searches the transform space once again for any small, hidden signals.

FKSCAN then outputs a bulletin for each data block citing detections and printing out the power spectral estimates of those signals. For each such signal there are also output spectra of phase - velocity, back azimuth, and F-statistic as functions of frequency. (The F-statistic is a measure of the likelihood that detected correlations are genuine; i.e., not due to chance combinations of noise).

An auxiliary program called FKPLOT has been written which outputs contoured printer plots of cross-sections of frequency wavenumber spectra cut normal to the frequency

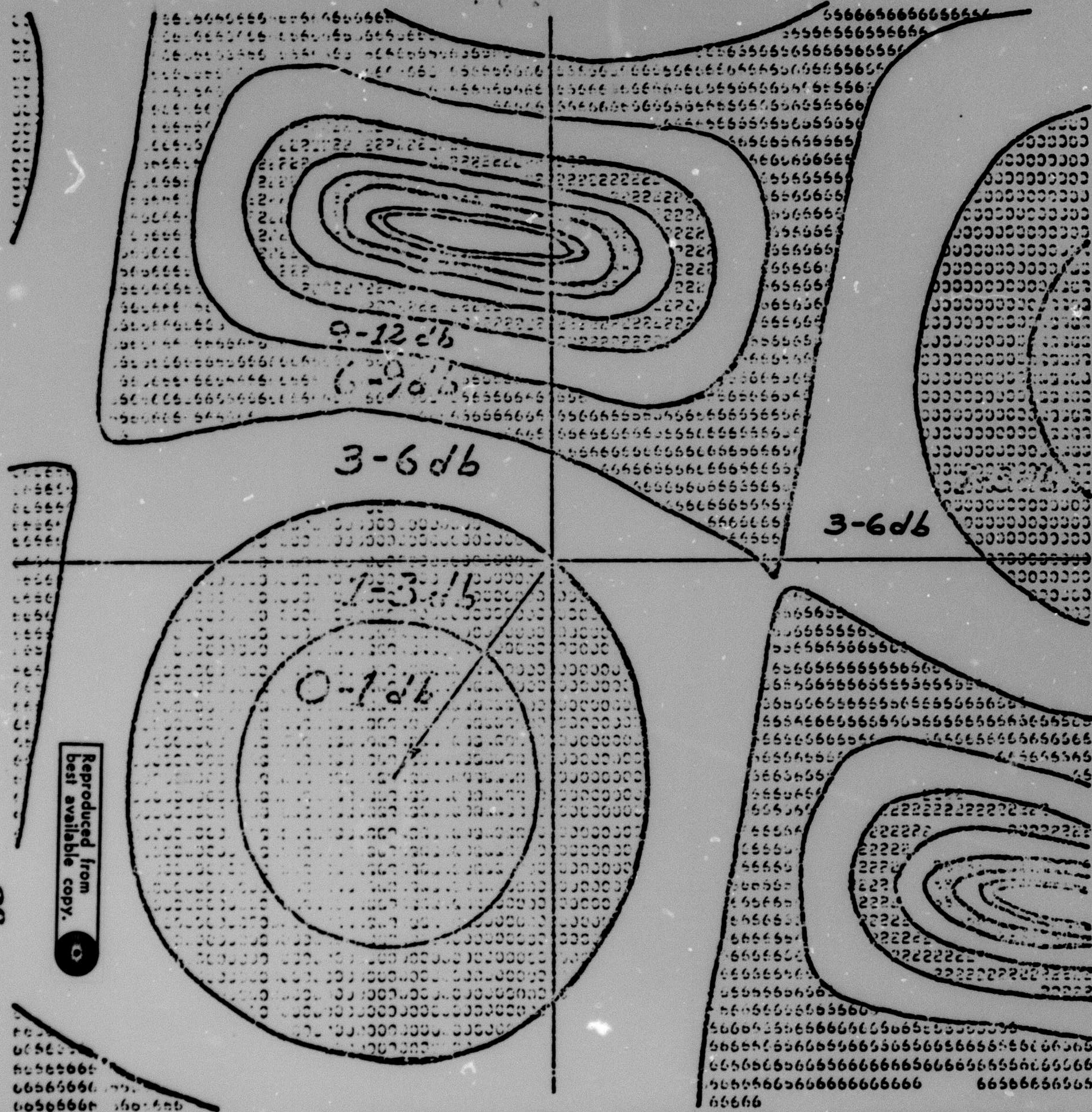
axis. An example of such spectral cross sections is given in Figure 20. The origin of k-space is at the center; the plot extends out to 0.13 cycles/km at the edges. The prominence at the lower left is infrasonic energy from the South Pacific as recorded at Grand Saline, Texas, 4 July, 1970. The vector from the origin to the peak indicates the phase-velocity and back azimuth: 331 m/sec, 217 degrees.

Estimating Magnitudes

A method for correcting the bias in Mb estimates has been described in a technical report to AFOSR. This report shows that observations from any seismological network lead to overestimation of the magnitude of seismic events which are near the detection threshold of that network. Methods are presented for calculating this magnitude bias. Consideration must be given to this effect in comparing networks with significantly different thresholds, in comparing theoretical and empirical estimates of network capability and in determining the source energy of small seismic events.

Model Studies

A two-dimensional model composed of aluminum and various thicknesses of vinyl has been constructed. Four discrete velocity zones are scaled to represent the oceanic crust, a



PERIOD = 46.55 SECONDS

SPECTRUM COMPUTED FROM DATA OF THE SMU 1973 GRAND SALINE INFRASOUND ARRAY. DAY 185, I.E., 4 JULY. THE TIME IS 0142'25 TO 0153'25 GMT.

LISTED BELOW FROM LEFT TO RIGHT ARE THE APPARENT PHASE VELOCITY IN KM/S, THE BACK AZIMUTH IN DEGREES EAST OF NORTH, THE POWER, AND THE F-STATISTIC OF THIS SECTION.

.331, 217, .377E 15, 5015

Figure 22

dipping lithosphere, a low-velocity zone, and a high-velocity mantle. Piezo-electric crystals are being used as source and receiver, and model seismograms are being recorded and digitized. The model is scaled such that Rayleigh wave energy in the range 20 to 200 kilocycles represents periods in the Earth of 10 to 100 seconds.

Figure 21 is a model seismogram from a surface vertical force showing that Rayleigh waves propagating over the laterally homogeneous portion of the model yield smoothly dispersed wave trains, encompassing the same period range as real Rayleigh waves. In addition to surface sources, horizontal and vertical forces have been located at scaled depths of 50 and 250 kilometers in the laterally homogeneous portion of the model. Spectra from the resulting Rayleigh waves compare closely with theoretically predicted spectra for an oceanic upper mantle model. For example, Figure 22 shows the Rayleigh spectrum for a horizontal force at a scaled depth of 250 kilometers and a scaled distance of 24°. The solid-lined spectrum was calculated from the model seismogram and the dotted curve is a theoretical spectrum for the same depth source orientation taken from Harkrider and Anderson (1966), after adjustment for the model source spectrum and for the

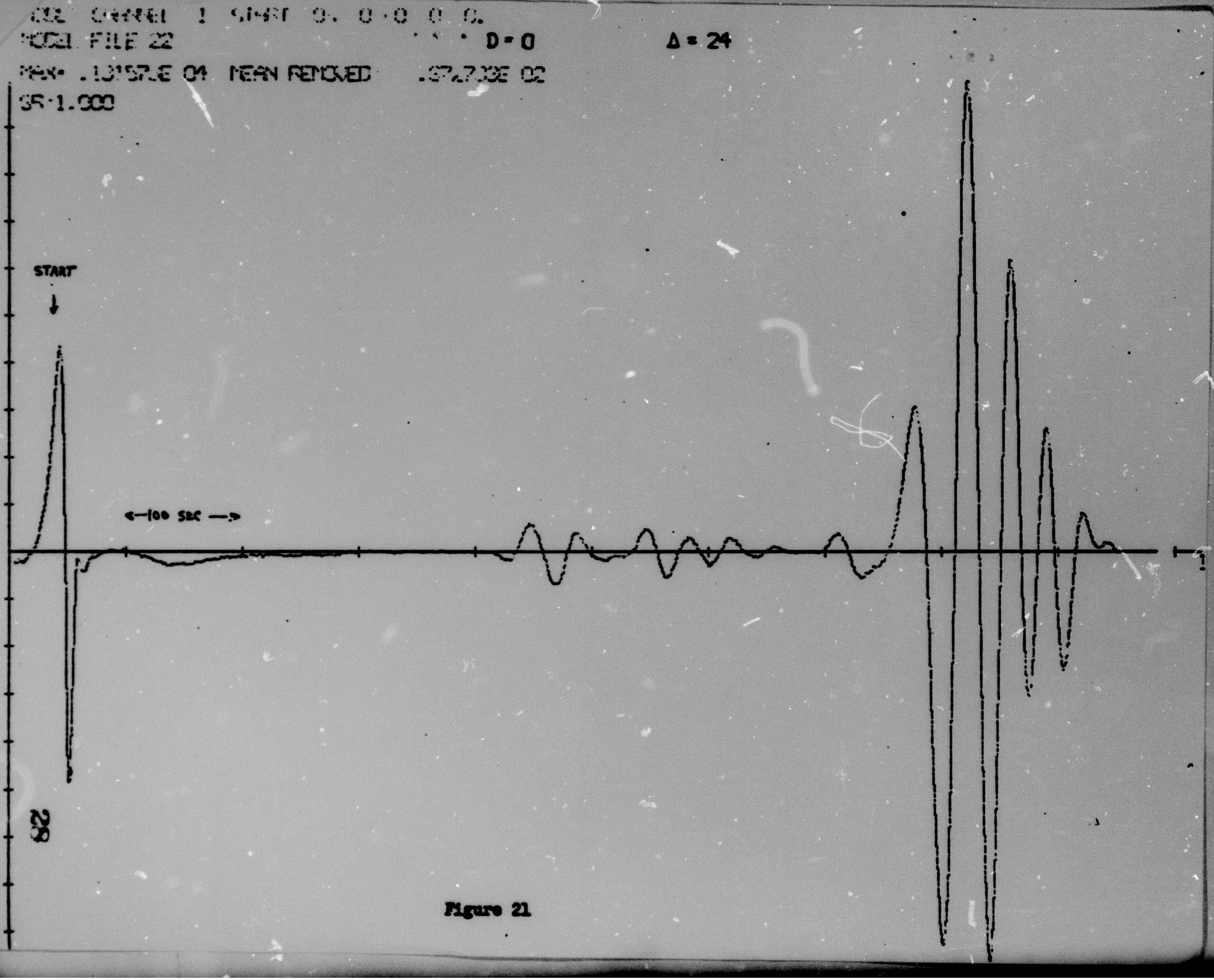


Figure 21

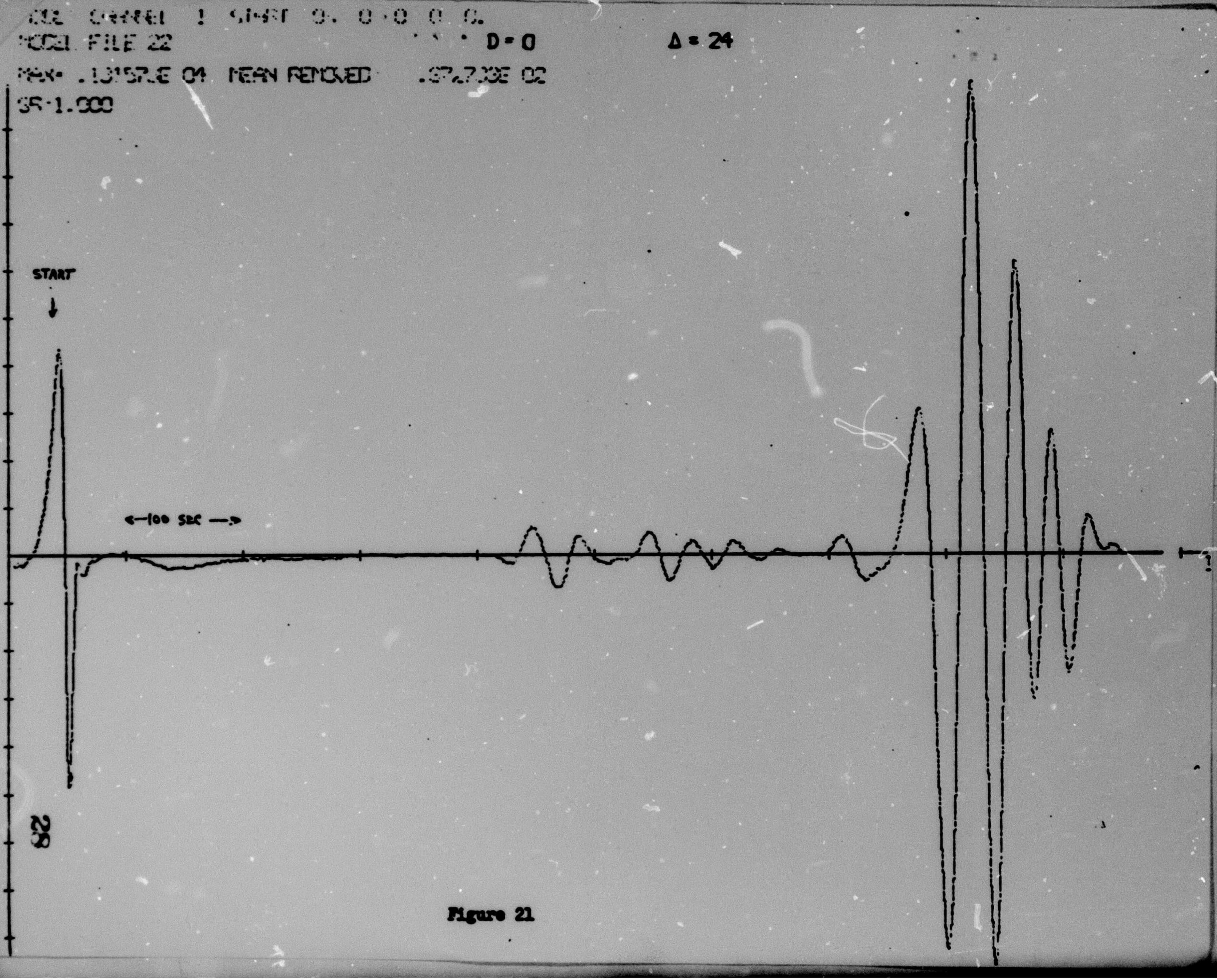


Figure 21

model attenuation characteristics. The two spectra are almost coincident in the passband 30-100 seconds, indicating that model and theoretical results for laterally homogeneous source areas and travel paths are mutually supportive. Below a period of 30 seconds, the model signal spectrum becomes lost in the noise

The next step will be to locate sources at the same depths in the downward bent lithospheric wedge. Comparison of the resulting Rayleigh spectra with those previously derived for sources in laterally homogeneous zones should determine whether or not the downgoing lithosphere acts as a waveguide to the surface for shorter period energy, and consequently determine to what extent theory based on laterally homogeneous media is adequate to predict spectra in more realistic earthquake source areas.